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M. B. Ettinger, et al

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

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A CRITICAL REVIEW OF THE LITERATURE OF 1955 ON WATER POLLUTION

by

M. B. Ettinger, C. Henderson, A. Hirsch, P. Kabler, M. Katz, G. H. Paine, R. C. Palange, C. M. Palmer, C. M. Tarzwell, W. W. Towne, E. C. Tsivoglou, J. W. Wiseman, and R. L. Woodward

BIOLOGY

Water Supplies

One of the outstanding problems created by the addition of wastes to our water courses is their effects on our water supplies. These effects may be either direct, such as materials which produce taste and odor, increase the dissolved solids, acidity, alkalinity or turbidity; or indirect, such as the promotion of the growth of interference organisms through a fertilizing effect. Organisms in water supplies can lead to a variety of problems (144) among which are tastes and odors, clogging of filters, growths in pipes, cooling towers and reservoirs, production of floating mats, infestations in purified water, changes in water quality as pH, hardness, turbidity, etc. and the production of toxicity. Some of the problems produced by organisms in water supplies are described and summarized by Palmer and Tarzwell (144) who also list specie characteristics of polluted and clean water and present 6 colored plates of algae which illustrate 132 species important in water supplies. Some of the beneficial effects of algae and algal control are also discussed.

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Tastes and Odors

It is reported by Swartz (189) that microscopic organisms are the most common cause of objectionable taste and odor in surface waters or in ground water stored in open reservoirs. It was found that many of the organisms have seasonal peaks in abundance. Optimum temperatures for diatoms were in the range of 40 to 60° F. Odors produced ranged from aromatic to fishy and were noted when population levels were at 2000 standard units per ml. or above. Optimum temperatures for blue-green algae ranged from 60 to 80° F. At low concentration these algae are reported to cause a grassy or mouldy odor while at higher concentrations a pig pen odor was evident. The green algae, which had optimum temperature of 50 to 70° F., produced a grassy or nasturtium odor at high concentration. The yellow-green algae (Chrysophyceae) are cold water forms (40 to 50° F.) which are most abundant in early spring. They produce odors which are noticeable even at low concentrations of organisms. The dinoflogellates are likely to occur at any time.

Water supply problems have arisen due to the pollution of the Elbe by untreated sewage and industrial wastes (68). Experiments indicated that taste and odor caused by the decomposition products of algae were not sufficiently reduced by chlorine dioxide, while experiments with filtration through absorptive material were successful. Hettche (95), however, reported just the opposite for Elbe River water, stating that chlorine dioxide at 0.8 p.p.m. removed odor.

Laboratory studies showed that the odors produced by two species of Oscillatoria were associated with changes in metabolism (205). When starved or when the nutritive medium was abruptly changed, O. splendida produced earthy odors. It was stated, however, that simultaneously the medium became turbid with slime produced in autolysis and that the odor was noted when the cells were damaged by maceration, desiccation or supercooling. Under alkaline conditions with increase in temperature and when undernourished, O. aghardii produced a rotten fruit odor. Growth of both species was stimulated by organic matter, phosphorus and nitrogen. These findings were confirmed by two other Russian workers Baslavskaya and Kislyakova (25) who reported that when nitrogen and phosphorus are introduced simultaneously, there is an increase of photosynthetic activity.

Ohle (139) on lake eutrophication studies, reported that a sewage plant effluent discharged into a lake caused such vigorous growth that the effects of secondary pollution were similar to those of pollution by untreated sewage. Investigations were made on effects of different substances on algal growth. It was found that the addition of ammonium and phosphate ions caused vigorous growth of unicellular green algae and that algal development and content of chlorophyll were highest in the presence of both phosphate and nitrate. The author believes that the nitrogen demand of both oligotrophic and eutrophic waters can be satisfied under natural conditions, but the national supply of phosphate is small and the optimum amount for vigorous algal growth is only reached by the addition of human wastes. Further, the addition of phosphate is regarded as the initial and main factor in the development of eutrophic conditions.

Filter Clogging and Growth

Hofmann (99) describes the difficulties that were encountered at the St. Gallen water works which treats Lake Constance water by rapid followed by slow sand filtration. A comparison is made between the pore size in filters containing sand of different sizes and the size of the organisms present in the lake water. Diatoms such as Tabellaria and Fragilaria were retained to a large extent in the rapid sand filter but more spherical shaped types such as Cyclotella passed through. The rapid sand filter reduced the plankton count 88.3 per cent in 1952 and 92.7 per cent in 1953. Studies indicated that in October and November 1953 the rapid sand filter removed 95 per cent of the filterable material from the raw water. It was found that the coarser sand (1.2 mm) was more efficient and effective.

Bottom-living algae were collected from 8 slow sand filters of the Newcastle and Gateshead Water Company at Whittle Dene, England (41). Throughout most of the year diatoms dominated the flora and there were spring and autumn maxima and a midsummer minimum of numbers. Marked differences were found in the composition of the flora of recently cleaned beds and those which had been in use for some time. Species present in the recently cleaned beds were found rarely or not at all on "older" beds. The protozooa population increased with time and their increase coincided with the decline of bottom-living diatoms.

Growths and Deposits in Pipes

The deposits in water mains from Warche and Gilippe Dams (Belgium) consisted mostly of Mn_3O_4 or MnO_2 and were due primarily to biological

action (206). Of the dried deposit, Mn_3O_4 represented 55.57 per cent; Fe_2O_3, 3.43 per cent and SiO_2, 6.04 per cent. Cellulose comprised 1.61 per cent of the wet deposit. After 16 years, the deposit was approximately 16 mm thick. It was calculated with 70,000,000 cu. meters of water passing annually through the conduit, 0.35 cu. mm. of deposit was formed by each liter of water. Although the water contained even 10 times more Fe than Mn in certain cases, the latter was selectively precipitated. The author believes that Leptothrix bacteria oxidize Mn. salts to Mn_3O_4.

Control of Nuisance Organisms

At Norwich, England, Nais worms together with smaller number of nematodes, diatoms, flatworms, rotifers, Cyclops and Daphnia were found in the distribution system after the water had passed through a slow sand filter (110). Treatment with high concentrations of Cl and $CuSO_4$ failed to give more than temporary relief. The microstrainer with apertures of 23 μ is being installed between the slow sand filter and the post chlorination tank, since results with an experimental microstrainer indicated that it was successful in removing the organisms from the water.

In September 1953 many bristle worms, Nais, of about 1 cm. in length were found in the covered swimming pool at Oldenburg, Germany (7). One liter of sodium hypochlorite to 90 cu. meters of water killed the worms in the pool but not in the filter. Even much greater concentrations, 7 l. to 9 cu. meters, were unsuccessful. When 7 l. of Lysolin were mixed with 30 cu. meters of water and continually circulated through the filter, positive results were obtained. It appeared, later, that in water with very low turbidity the worms died and disintegrated without the addition of chlorine.

Dias (61) reports that a culture of Bacillus pinottii and peptone was successful in the control of certain mollusks. Certain non-sporulating bacteria cultivated in sugar, caused perforations in the shells and death of many mollusks. Foci of Planorbidae may be extinguished by application of Saccharomyces cerevisiae and sugar or mollasses in a relatively high concentration. A rapid extension of two foci of Australorbis nigricana was obtained by 2 treatments with distillery syrup. Such methods are, of course, not practical in most water supply systems.

Bringmann (38) reports that ozone destroys resistant spores of soil bacteria in 14 minutes at a final concentration of 0.35 mg. per liter. Experiments also showed that ozone was lethal to unicellular algae, Ankistrodesmus, other phytoplankton, Volvox and Euglena; zooplankton, Daphnia and Cyclops, and to larger animals such as fly larvae, tubifex worms, and water mites.

In experiments (103) on the toxicity of quaternary ammonium compounds to algae and fish, it was found that such compounds were lethal to fish at concentrations of 1 to 4 mg. per l. at 20° C. depending on the length of the alkyl chain. It was concluded, however, that quaternary ammonium compounds in concentrations of 1.2 to 2.0 mg. per l. can be used to control algae without permanent injury to fish.

Palmer and Maloney (143) reported on the screening procedures used in testing candidate algicides. The screening procedure involved the addition of 2 p.p.m. of the gross material under test to the culture medium previous to its inoculation with a particular alga. Results for

76 substances were tabulated. Inorganic and organic salts, rosin amine compounds and antibiotics tended as groups to show high toxicity. In general, the more sensitive algae were Microcystis, Nitzschia, and Gomphonema, while the resistant genera were Scenedesmus, Chlorella, and Cylindrospermum.

Delrad 70 (Rosin amene D acetate, 70% solution in water) at concentrations of 0.25 to 0.50 p.p.m. of active ingredient killed Ulothrix in 5 to 6 hours with no apparent deleterious effects on brook trout fingerlings. The hatchery water had a temperature of 48 to 50° F. and a total alkalinity of 127 p.p.m. Although Ulothrix declared, diatoms increased (106).

Since its introduction in 1937, sodium pentachlorophenate has been successfully used for the control of slime and algae in cooling water systems when used at concentrations of 15 to 20 p.p.m. (216).

Copper sulphate gave incomplete control of plankton algae in the Philadelphia Reservoirs, particularly when growth was stimulated by the addition of sodium hexametaphosphate, which was used to increase the pH and reduce the corrosiveness of the water. Chlorine dioxide gave almost complete control of the algae under this condition (167).

Toxic Algae

Rose (170) reported a heavy mortality of wildlife and livestock at Storm Lake, Iowa in the fall of 1953. Death of the animals was attributed to their drinking water containing toxic blue-green algae, Anabaena flos-aquae. To prevent a recurrence of the trouble in the fall of 1953, the lake was sprayed with $CuSO_4$. Practically no Anabaena developed and

there was good control of Aphamzomenon and Microcystis which at times developed in great quantities. Care has to be used in the application of $CuSO_4$, as experimental data show that quantities as low as 0.5 p.p.m. are to the newly hatched Stizostideon vitreun and some fish food organisms, particularly Daphnia.

Fish kills associated with the red tides off the west coast of Florida are attributed to the high incidence of the marine dinoflagellate, Gymnodinum brevis. Wilson and Collier (217) report the development of methods for culturing the organism. Investigations seem to indicate that heavy rainfall and subsequent river discharge are instrumental in initiating blooms of G. brevis. Sea water containing 4 to 10 ml. of river water per 100 ml. supported limited growth, while 7 to 10 ml. of river water or peat extract per 100 ml. of sea water produced better growths. Laboratory cultures of G. brevis have attained concentrations of more than 2 million cells per l. and were toxic to Mollienesia and Mambras. Additional studies (204) have further confirmed the theory that river effluents containing organic nutrients when combined with the correct temperature and wind conditions produce a suitable environment for rapid reproduction of Gymnodinium brevis. Recently it was discovered in the Fish and Wildlife Service laboratory at Galveston that metallic copper in extremely small quantities is highly toxic to G. brevis (14). After further experimental work in the laboratory, metallic copper in the form of large screens and possibly copper ore tailing will be tried on a field scale to determine its control effectiveness as a substitute for the more expensive $CuSO_4$. In the meantime, control experiments using $CuSO_4$ will be continued.

Copenhagen (55) describes surveys made to determine the cause of fish kills off Walvis Bay, South West Africa, which occur most years and sometimes 4 to 5 times in a season. It was found that there is a definite relation between the fish kills and certain meteorological and oceanographic conditions which give rise to depletion of D.O. and development of sulphate-reducing bacteria with consequent production of H_2S. Blooms of toxic phytoplankton may also occur.

Stream Pollution

Surveys

Studies of the biological effects of pollution on the receiving water have been stressed in recent years. Attention is being directed toward water quality criteria for the protection of aquatic life and the effects of various concentrations of materials on different forms of life. Halsband (88) reported on investigations in Westphalia to determine the maximum permissible concentrations of impurities in streams which will allow the maintenance of normal aquatic life. To determine the degree of toxicity of a substance the oxygen consumption and breathing frequencies of the animals were measured and the threshold of disturbances determined. The Report of the British Water Pollution Research Board for 1954 (13) contains much valuable information on conditions in the Thames estuary since 1920 and the effects of pollution on fish in the River Colne. Special studies were made of the toxicity of undissociated ammonia at concentrations of 0.9 to 2 p.p.m. and higher, and the effects of CO_2.

The Rhine is a major source of water supply for some parts of Holland (114). Its B.O.D. is higher than is usually permitted in potable waters. Further, average chloride concentrations have changed from an average of 37 p.p.m. in 1898 to 204 p.p.m. in 1953. Fishermen complain about decreased fish catches. In cold weather self-purification cannot cope with the pollutional load. The situation has become steadily worse since World War I and international cooperation will be needed to clean up the stream.

Trama reports (190) that in Japan sulphate paper mill waste may be detrimental to fish life in the following ways: (1) by depleting the dissolved oxygen and suffocating fish; (2) by direct poisoning or killing of fish by toxic substances and (3) by tainting the fish flesh so they are of no use for food.

Studies were made to correlate the invertebrate bottom fauna of San Francisco Bay with a variety of factors (74). The effects of pollution were the only ones which were obvious. In portions of the estuary where industrial wastes are released the depressing effect on the fauna was apparent. Domestic wastes depressed the fauna but not as much as the industrial wastes.

Algal studies in the River Colne by means of the immersed glass slide technique indicated that the material collected on the slides and the natural flora are at least qualitatively similar (12). It was found that there was a seasonal succession of forms. Chironomus riparius was found in the alpha meso-saprobic zone below sewage outfall. Their development and subsequent emergence as adults represents a considerable loss of

organic matter from the river. Distribution of animals in the bottom deposits were studied by means of core samples and by submerged traps. In favorable stretches of the river there were 20,000 Chironomus riparius per square meter in 1955. Much higher densities, up to 300,000 per square meter, were found in the spring of 1954. Asellus reached a density of 60,000 per square meter in February 1955 and exceeded 200,000 per square meter in the spring of 1954.

Natural Purification

Natural purification consists largely of the utilization of organic wastes by living organisms. Such wastes are thus food for organisms and have a fertilizing effect which increases productivity and may lead to extensive and troublesome growths. Recently, development of Sphaerotilus has caused trouble in the Columbia River. Such troubles are quite widespread, as indicated by Popp and Bahr (155) who describe the mass development of Sphaerotilus natans in the River Oker during the sugar campaign of 1952. Quantitative measurements were made by determining dry weight, which was taken to be 8 per cent of the wet weight. Development during this season was of such an extent that it disturbed biological conditions of the stream. It was concluded that the Sphaerotilus developed from its "scarcity" form, Cladothrix which is always present. Sphaerotilus flocs di did not decrease in amount for some distance down stream below the beet sugar factories, showing that there was still vigorous growth on the strear bed. The Sphaerolitus floc settled out to form a sludge, the effects of which continued into the next summer so that the process of self-purificatior

was retarded and only reached its full effect in late summer shortly before the start of the next sugar campaign.

Liebmann (123) concluded that the presence of amino acids in dilute solution is essential for the development of Sphaerotilus natans. Drifting masses developed best at low water temperatures and at a rate of flow not less than 20 cm. sec. Nutrient conditions are best below the discharge of sewage plants, waste water from cellulose manufacture, sugar factories and milk processing plants. In small shallow streams masses develop most freely on the bed and banks, but in large streams masses may also develop in the open water. Examinations of growths in the Danube below a pulp mill showed that conclusions as to the age of flocs could be drawn from the living organisms in them. Flocs were found in the open water 100 meters below the plant, and large flocs were present at 500 meters, while growths on the bank were still small. At 100 meters, the flocs were composed of sprouting filaments with white growing points and contained only a few bacteria; at 200 meters the number of bacteria had increased; at 300 meters the flocs were about 3 cm. in size, had a brownish center and contained numerous bacteria, a few flagellates and ciliates; at 1 km. they contained a community regarded as typical. The typical community remained present over a stretch of 1 to 10 km. corresponding to a time of flow of 20 min. to 3.5 hrs. From 10 km. to about 33 km. downstream, the growths became darker and looser in formation and the organisms changed. In large deep streams about two thirds of the living fungus is carried by the water near the stream bed.

The conclusions of various investigators in regard to the relation between Sphaerotilus natans and Cladothrix dichotoma were described by Bahr (20). Observations on the Oker and its tributaries could only be explained by the assumption that Cladothrix which occurred less frequently than Sphaerotilus, but was present at all seasons, is the form of Sphaerotilus which occurs during unfavorable environmental conditions. Mass development of Sphaerotilus followed the sudden addition of large quantities of nutrient material from sugar factories. Culture experiments with both forms gave first, on solid media, pure cultures of Cladothrix dichotoma. In liquid media with added asparagen the Cladothrix form could be converted to the Sphaerotilus form if the nutrient solution was frequently renewed. By re-inoculation on to the solid medium the Sphaerotilus form returned to the Cladothrix form. Bahr discusses this same subject in another paper (19). It is pointed out that in lakes or stagnant water eutrophic conditions are produced by a gradual accumulation of nutrient materials, but in streams the optimum concentration of nutrient matter is reached by dilution of concentrated organic or inorganic matter. Such conditions are common in rivers polluted by sewage and lead to mass development of bacterial growth, the most vigorous of which is Sphaerotilus natans. Dense growths of the organisms lead to the production of a sludge in which other organisms develop, especially sulphur bacteria.

The enrichment of streams by sewage plant effluents is well illustrated by the appearance of perch and pike in Lake Windermere (15). During the last 40 years there has been a progressive increase in the

plankton population with the increase in the amount of sewage works effluents and the amount of calcium salts washed in from surrounding agricultural land.

Organic Enrichment

Ohle (138) describes the changing conditions in a number of lakes in Holstein due to growth of population and agricultural development. Phosphate is considered the most important nutrient material but sulphates are also considered. The rapid aging or eutrophication is described by the same author in another paper (140). It was observed that lakes in Holstein and Lake Ploner had been aging rapidly during the past few years. This accelerated aging is ascribed to increases in nutrient matter contributed by sewage, industrial waste waters and drainage from manured fields, the most important constituent being phosphate.

Biological Indicators of Pollution

A physical, chemical and biological study of 55 sampling stations was made 3 times during 1954 in the Long Beach - Los Angeles Harbor area (160). On the basis of D.O., there appeared to be only 2 pollutional divisions, clean and polluted. However, based on the abundance of selective species of Polychaeta, 5 categories of bottom were recognized; healthy, semi-healthy I, semi-healthy II, polluted and heavily polluted. Macro-invertebrates were completely lacking in the latter area which was characterized by the preserve of sludge beds. There was a progressive decrease in the number of Polychalte species from the healthy to the very polluted as follows 7-5-5-3-0. Pollution selective species decreased with decreasing pollution.

Stammer (183) investigated the effects on indicator organisms of different classes, from H_2S and ammonia. These studies were designed to discover whether there was any connection between the resistance of organisms to these substances and their position in the saprobic system, whether the threshold of toxicity of ammonia was low enough for this to be regarded as a factor in the distribution of organisms apart from the different oxygen requirements and whether indicators of polluted water had greater resistance to H_2S in the absence of oxygen than had unpolluted water forms. Fourteen indicator forms including insect larvae, annelids, turbellaria, and protozoa were tested. In tests with H_2S all protozoa, regardless of their position in the saprobic system, had low resistance in the absence of oxygen. With 10 mg. of H_2S per l. poly and alpha meso-saprobes resisted the poison for 14 hrs. to 5.5 days; beta meso-saprobes for 3 to 13 hrs. and oligo-saprobes resisted for 1.5 to 6 hrs. There was a clear relation between the effect of ammonia and the position of the organisms. The results suggest that the preserve of poisonous products of decomposition would have the same effect, on organisms of the unpolluted water zone, as reduction in the concentration of D.O. Oxygen content would be the decisive factor in slow flowing or stagnant water, while poisons, especially ammonia, might be the main influence in polluted but rapidly flowing and therefore oxygen rich water. Some organisms are, however, indicators of the presence of D.O. but not of the purity of the water.

Biglane and Lafleur (32) used bottom fauna in the classification of streams. Waste from a Kraft pulp and paper mill were toxic to mayfly naiads and unionid clams while phenolic waste waters from a plant for creosoting wood eliminated crayfish, leeches, clams and snails but sewage fungus, annelids and chironomids appeared in the area of greatest pollution. In a third stream high salt concentrations resulting from the discharge of brines from oil fields were lethal to crustacea and many insects. The number and type of fish showed close correlation with the bottom fauna but some fresh-water fish showed adaptability to high concentrations of NaCl.

An extensive pollutional investigation was made of western Lake Erie during 1927 to 1929 (218). An index of pollutional conditions was set up. A mud bottom having less than 100 tubificid worms and more than 100 Hexagenia nymphs per square meter was considered free from pollution. Three degrees of pollution, based on numbers of tubificids per square meter, were recognized: light pollution, 100 to 999; moderate pollution, 1000 to 5000; heavy pollution, more than 5000. While some areas of pollution were found near the Maumee and Raisin River mouths, it was concluded to be highly improbable that pollution in the western end of Lake Erie had been the controlling factor in depletion of the fishery.

Beck (28) proposes a simple biotic index for indicating biological conditions in Florida streams. The index may occupy any value ranging from 0 to about 40. The lowest value for a clean stream is 10. A grossly polluted stream will have an index of 0 and a moderately polluted stream 1 to 6.

Knopp (113) proposes a quantitative method for indicating biological conditions in the various zones of a polluted stream. His scheme is based on Kolkwitz and Marsson's classification and a survey of a long section of the River Main. For each station the number of organisms typical of each of the four pollutional zones is listed and the biological conditions of the station evaluated by means of a formula.

Sundene (188) sets forth the results of ecological studies of the algae of Oslo Fjord during 1940-1942 and 1947-1952. The inner basin receives untreated or coarsely screened sewage from Oslo and its neighborhood, which leads to more general eutrophic conditions. Planktonic organisms thrive in the polluted inner areas causing a decrease in the transparency of the water and cutting off light from the sublittoral zone which has an extremely poor algal flora. Braarud points out (37) that oxygen deficiencies have been observed in the deep waters of Bonne Fjord, a branch of Oslo Fjord, and that deep sea prawns and zooplankton have been killed. In the inner part of Oslo Fjord, cod have shown satisfactory growth but hatching of the eggs has been impaired. Gaufin and Tarzwell (80) describe environmental changes which take place in a polluted stream during winter. It was observed that stream flow is greater, metabolic activity is at a lower level, life zones become longer and diurnal variations in D.O. are at a minimum. Due to these changes organic materials are carried further downstream and the pollutional carpet of bacteria, protozoa and entrapped organic materials may extend down to the clean water zone of summer, significantly reducing the macro-invertebrates which serve as fish food.

Wurtz (220) describes a modification of Patrick's method for the use of aquatic populations to indicate pollutional conditions. Illustrations of the use of the method are given.

Fish Kills

The dewatering of a clay mine at Conway, Pennsylvania resulted in an extensive fish kill in a 70 mile stretch of the upper Ohio River (9). Excess acid was blamed for the kill which was most severe in the East Liverpool - Wheeling area.

Release of irrigation water from Alcova Dam killed many aquatic insects and fish in the North Platte River (120). As the released waters moved downstream the color of the stream changed to yellow, then brown and finally grey. In 16 hrs, the D.O. dropped from 9.3 p.p.m. to 0.3 p.p.m. Large numbers of dead insect larvae were noted on the water surface and the fish died in live boxes.

Water Quality Criteria for Aquatic Life

An increasing interest is being shown in water quality criteria for the protection and maintenance of aquatic life in our waters. The progress report of the Aquatic Life Advisory Committee for the Ohio River Valley Water Sanitation Commission (16) sets up some base lines for the determination of criteria. A suitable habitat for fish is defined as one which produces a good crop as determined by census of catch, growth rate, condition and suitability of flesh. The range of pH in which direct lethal effects are not produced is indicated as 5 to 9.5, but it is

pointed out that pH greatly influences the toxicity of some materials; that sudden changes are not desirable and that from the standpoint of productivity it is best to maintain the pH in the range of about 6.5 to 8.2. For a well-rounded warm water fish population, it is recommended that D.O. levels shall not be below 5 p.p.m. for more than 8 hrs. in any one day and at no time shall they be below 3 p.p.m. It is recommended that the toxicity of wastes be determined by means of bio-assays and that water from the receiving stream be used in determining the dilution needed for a particular waste.

Temperature

Gibson and Fry (83) report the upper lethal temperature for lake trout as 23.5° C. The temperature for maximum activity is from 15° to 17° C. Bailey (21) reported that a water temperature of 38° C. resulted in high mortality of fishes confined in a shallow pond. Symptomatic of distress was a marked lassitude, loss of orientation, and reduction of swimming ability. The immature fish were the most resistant, while among the different groups the cyprinodontid, poeciliid, and centrarchid fishes were most hardy.

Dissolved Oxygen

Gibson and Fry (83) state that active respiration of one to two year old lake trout becomes dependent on the oxygen pressure at approximately 2/3 air saturation. The minimum oxygen pressure for the species is approximately 40 mm. Hg at 10° C. and 60 mm. Hg at 20° C.

A laboratory study was made at the Hawaii Marine Laboratory on Coconut Island to determine the oxygen requirements of bait fishes, particularly the iao (157). Lethal D.O. levels and rates of oxygen consumption under various conditions were studied. Oxygen consumption showed an increase with increased flow and the critical oxygen level was between 1.5 and 2.5 cc. per l. Individual iao showed marked differences in their resistance to D.O. deficiency, lethal levels ranging from 0.50 to 1.58 cc. per l. At the higher temperatures, in the range from 19° to 29° C., there was a rapid increase in the rate of oxygen consumption and a more rapid reduction of D.O. to a lethal level.

Burdick (44) showed that young shad may be present at oxygen levels even below 4.0 p.p.m. This appears to indicate that the figures given by Ellis et al., as a minimum for young shad, may not be applicable to all natural waters. It is concluded that the minimum standard of 4.0 p.p.m. of D.O. for warm fishery waters is adequate for waters containing shad.

Wickett (214) reports the oxygen demand of pre-eyed chum salmon eggs to be between 0.00013 mg. and 0.003 mg. per egg per hr. at temperatures of 0.1° to 8.2° C. A high percentage of eggs was found dead in certain heavily silted areas of the creek. This may be explained by very low concentrations of D.O. (0.2 p.p.m.) or very low velocities of water in the gravel (2 mm. per hr.).

It was determined experimentally (208) that certain marine animals show adjustments in their respiration; that is, oxygen consumption varies plus or minus proportionally with oxygen tension in the water. When the

O_2 tension decreases below a critical value, utilization decreases rapidly and the animals die within a comparatively short period. It was shown that this critical point of the O_2 tension of the surroundings is very low for the inhabitants of D.O. poor areas, and highest for those living in well-aerated habitats.

Nikiforov (135) found the maximum assimilation of O_2 occurs in young salmon at about 22 days after hatching, after which a decline sets in, followed by a small maximum at about 40 days; in a 50 to 60 day period a decided decline occurs (summer period), with a definite rise in 70 to 80 days. Differences in oxygen utilization (174) are also due to conditions in the habitat. At 20° C. the young of wild large carp utilize 310 to 452 mg. O_2 per kg. of wt., mirror car 220 to 260 and scaly carp 192 to 221 mg. Specimens from a water that is refreshed by flow show a substantially higher utilization than is displayed by specimens collected from ponds with relatively stagnant waters; the difference reached 50 per cent in extreme cases.

In experiments with trout in flows of water containing constant low D.O. concentrations (173) it was found that at temperatures of 9° to 10° C. young-of-the year trout could withstand oxygen concentrations down to 1.9 mg. D.O. per l. The 50 per cent tolerance level was 1.75 mg. D.O. per l. Acclimation to low oxygen levels occurred; for a drop of 1.0 mg. D. O. per l. in environmental D.O. concentration; the tolerance level decreased by approximately 0.09 mg. D.O. per l. and resistance times at given lethal levels increased up to five fold.

Between 20 to 33 hours were required for the fish to acclimate to a change of 1.0 mg. per l. in the D.O. concentration of the environment. Acclimation to low levels of oxygen was accompanied by an apparent increase in the ability of the animal to remove oxygen at low D.O. concentrations. The tolerance levels of small fish were similar to those of large fish at similar acclimation levels.

Troiani (202) found that at 10° C. the average consumption of O_2 by Gammarus pulex is 1350 cu. mm. per gm. dry wt. per hr. The intensity of respiratory metabolism increases with temperature to the lethal temperature of 30° C. and decreases with decrease in tension of D.O. below 3 to 4 cc. per l.

Unusual thermal stratification was observed in Western Lake Erie during the period September 1-4, 1953 (40). Concentrations of D.O. as low as 0.70 p.p.m. were found near the bottom. Bottom samples collected on September 5, 1953 revealed a total of 465 dead Hexagenia rigida and H. limbata occulta nymphs per square meter. In 61 bottom collections made over a wide area between the Canadian shore and Catawba Island on September 14-26 and November 13, 1953 the average population of living nymphs was 44.3 per square meter, a great reduction. Bottom fauna collected from the same area in 1954 (39) indicated that a few nymphs were again inhabiting the area.

Studies were made of the oxygen requirements of 6 species of caddis flies from the River Blyth, Northumberland (149). Oxygen determinations showed little differences in D.O. in the swift flowing

shallows and deeper slow flowing stretches. It was found that some larvae dependent upon current for feeding and larvae readily immobilized at a relatively high D.O. concentration in still water can tolerate low concentrations in flowing water. Current is therefore of prime importance in the distribution of larvae.

Job (104) made a detailed study of the oxygen consumption of brook trout. The consumption of wild and hatchery stock ranging in size from 4 gm. to 1000 gm. was measured after appropriate acclimation at 5°, 10°, 15°, and 20° C. The periods of survival of rainbow trout in concentrations of un-ionized NH_3 in the range of 0.86 to 1.96 p.p.m. of N increased as the concentration of D.O. was raised from 1.5 to 8.5 p.p.m. (66). At each concentration of D.O. the period of survival decreased as the concentration of un-ionized NH_3 increased from 0.86 to 1.96 p.p.m. The effect of greater D.O. in increasing survival time was greater in the lower concentrations of un-ionized ammonia. Results of experiments reported by the Water Pollution Research Board (60) indicate that the period of survival of trout in a given concentration of undissolved NH_3 increases markedly with increase in the concentration of D.O. Thus any reduction in the D.O. in a river may increase considerably the toxicity of NH_3.

Settleable Solids

Monthly bottom samples were collected from Shape Creek between October 1952 and June 1953 to indicate the effects of silting on the benthic fauna (193). Below the mouth of a tributary from an eroded area

the population was 7.3 organisms per sq. ft. while above, it was 25.5 organisms. Studies in Oklahoma have disclosed similar effects of turbidity and silt (73). Nineteen paired ponds were studied and the findings were as follows: fish grew more rapidly in the clear ponds; bass increased 6.5 times in clear ponds, 4.0 times in intermediate ponds and 1.25 times in muddy ponds, over their beginning size. Bass reproduced in 7 of 8 clear ponds; in 4 of 10 intermediate ponds and in none of the muddy ponds. Plankton was 13 times and 1.5 times more abundant in the clear and intermediate ponds respectively than it was in the muddy ponds. These conditions are duplicated in the larger lakes. Fishing success is greater in the clear lakes.

Bio-assays and Toxicity

Freeman (76) outlined the techniques employed in estimating the extent of pollution of surface waters by the discharge of trade waste waters, based on their toxicity to fish and other aquatic fauna. Bandt (22) gave a discussion on the application of toxicity bio-assays in practical fisheries work, fish cultural activities and search for causes of fish kill. Leclerc and Devlaminck (119) described the equipment, type of fish, method of acclimatization and method of observation used by C.B.E.D.E. in testing the toxicity of substances to fish. An attempt is being made to develop a standardized procedure to compare results of toxicity tests made by workers in Switzerland, France and Belgium.

Phenols

Trama (201) ran bio-assays in a modified artificial dilution water to test the toxicity of phenol. Fish were transferred to new solutions every 24 hours as the loss of phenol under test was about 2 p.p.m. in the first 24 hours. For bluegills the 48 hr. TL_m was 20.5 p.p.m. $\pm$ 2 p.p.m. and the 96 hr. TL_m was 19.3 p.p.m. $\pm$ 2 p.p.m. Fish reacted to all concentrations of phenol from 15 p.p.m. upward but did not react at 10 p.p.m. Survival for 96 hrs. at various concentrations were as follows: 15 p.p.m., 100 per cent; 17 p.p.m., 70 per cent; 20 p.p.m., 50 per cent; 26 p.p.m., 10 per cent and 28 p.p.m., all dead within 24 hrs. In the Pliesse below Leipzig when D.O. increased to 5.3 p.p.m. and the phenol decreased to 4.3 p.p.m., the first protozoa and algae appeared and increased in variety and quantity as phenols were reduced to 0.2 p.p.m. (10). According to laboratory tests selected protozoa tolerated phenolic compounds up to the following concentrations in p.p.m.: phenol and cresols, 300; pyrocatechin, 150; resorcinol, 600; phloroglucinol, 650; pyrogallol, 33; hydroquinone, 6.0 and phenol waste concentrate, 13. Toxicity increased with temperature.

Bandt (23) reviewed the literature on the effects of phenol on fish and other aquatic life. He found that: they were toxic, repelled fish, affect flavor and kill fish food organisms. Pure phenol is lethal to trout at 9.5 p.p.m. and to tench at 12 p.p.m. It taints fish flesh at 25 mg. per l. while the level is 10 mg. per l. for cresol. These materials kill Gammarus at 25 mg. per l. and Tubifex at 200 mg. per l.

Data available in the literature on the toxicity of other phenolic compounds are summarized. Some 15 compounds are listed. The author believes that the fish acquire the phenol taste from eating Tubifex. Tainting of fish flesh is most serious when there is an ice cover.

Meissner (129) reported on the toxicity of oxidation products of hydroquinone to protozoa bacteria, rotifers, crustaceans and molluscs. Relative toxicities as compared to phenol or several phenol derivatives are given in tabular form.

Ammonia

Bastos (26) reports that in a 13-day test NH_3 killed 47.8 per cent of "piabas" when present at 5.2 p.p.m. He states that size and weight do not influence the resistance to toxicity. In concentrations up to 30 p.p.m. CO_2 reduces the toxicity of undissociated ammonia by lowering the pH value of the water and then increasing the degree of ionization of ammonia (65).

Insecticides

A synopsis of the papers presented at the 1955 A.C.S. meetings contains much information on toxicity (3). Chlorinated benzenes are among the most troublesome materials. In California, fish have been killed by rice field application of Dieldrin at the rate of 0.5 lb. per acre. A concentration of 0.64 p.p.m. was found in surface waters, and this was rapidly lethal, considering that 0.016 p.p.m. is significantly toxic. Other materials causing problems were toxaphene, D.D.T., and rotenone.

At 47° to 49° C. the 24, 48 and 96-hour TL_m values of malathion to fall chinook salmon were as follows: 0.17, 0.15, and 0.12 p.p.m. repectively (148). It was further determined (105) that the toxicity of solutions of malathion does not change, at least during the first 14 days after preparation.

Investigation of the stream bottom fauna in a 52,000 acre watershed near Wilkes Barre, Pa., which received an aerial spray at the rate of 1 lb. of D.D.T. per acre, showed that the number and volume of benthic forms were rapidly reduced (98). However, depopulation was not complete but some sensitive forms such as the trichoptera did not reestablish themselves for some time.

Two months after D.D.T. was sprayed over a forested watershed in New Brunswick for budworm control, fingerling salmon were virtually absent (215). Although heavy mortality followed the spraying, delayed action covered many deaths up to 4 months. Most of the immature stages of fish food insects were killed.

Hooper and Hester (100) report that bottom samples taken in 36 North Alabama streams 3 years after an extensive kill due to cotton dusting with toxaphene and other insecticides indicate that the toxicants were no longer present. Rotenone studies indicated a fish population made up largely of rough species.

When waste waters from a plant producing contact insecticides were passed through a sewage treatment plant, they eliminated the typical organisms of the filters, humus tanks and receiving stream (154). Even

tubificid and chironomids were affected and fish showed effects specific for hexachlorcyclohexane.

Cyanide

Wuhrmann and Woker (219) report that with a decrease of O_2 tension the toxicity of CN increases at all temperatures. The temperature coefficient for the speed of action of CN is dependent upon concentration, while the retarding action of higher $D.O.$ concentrations upon toxicity decreases with increasing concentrations of CN.

Renn (162) found that under conditions which prevent the loss of volatile toxic components young fresh water fish react adversely to KCN concentrations exceeding 0.03 to 0.05 p.p.m. N as CN. Lactonitrile gave values only slightly less than those for KCN but the fish tolerated much higher concentrations of acrylonitrile.

Downing (65) found that the survival times of rainbow trout in KCN solutions in the range of 0.0105 to 0.155 p.p.m. CN increased with increase of $D.O.$ concentrations between 10 and 100 per cent of air saturation values, the effect being most marked with the lowest concentrations of CN. Herbert and Downing (93) report in more detail on the survival of rainbow trout in KCN solutions.

The toxicity, to the western blacknose dace, of KCN and potassium cuprocyanide having CN to Cu M-ratios of 4.0, 3.75 and 3.0 were measured by a flow-through procedure (124). The toxicity decreased as the ratio of Cu to CN increased with the 24 hour TL_m for KCN and the 4.0, 3.75 and 3.0 M-ratios being 0.22, 0.38, 0.47 and 0.71 p.p.m. respectively. In

spite of the decrease in toxicity due to the presence of Cu, cuprocyanide solutions are sufficiently potent to constitute a pollutional hazard when present in industrial wastes.

Other Material

Tests of the relative toxicity of the various members of the homologous series of alkyldimethy-benzyl-ammonium-chlorides to sockeye salmon indicated that toxicity rises with the increase of chain length to a maximum with the hexadecyl homologue and drops off somewhat with the octodecyl homologue (171). Four tables are given showing the toxicity of the various materials to fish.

The toxicity of slime control agents to Notropis atherinoides and N. cornutus were determined and related to their bacteriostatic and fungistatic properties (207). The minimum lethal concentrations in p.p.m. of the various substances were reported to be as follows: BSM 11, 0.8; Buffen 30, 0.02; Butrol, 0.5; Dowicide G, 0.05; Pyridylmercuric acetate, 0.15; Pyridylmercuric chloride, 0.04 and Roccal, 10.

Toxicity tests (11) showed that automobile gasoline and jet aviation fuel are more toxic to salmon fingerlings than diesel-truck oil and sludge oil. Surface films of the first two were lethal at 5000 and 10,000 p.p.m. while agitated solutions were lethal at 100 and 500 p.p.m. respectively.

The high content of magnesium salts and chlorides discharged from a potash works killed fish and exercised a selective effect on the benthic fauna of the Werra and Wipper (1). The gammarids and the small organisms are the most sensitive and were eliminated first. The increase in salt

content resulted in a population consisting of 90 to 98 per cent tendipedid larvae and resulted in a population with few species but large numbers of individuals. The saprobic system was still recognizable till a chloride concentration of 3000 p.p.m. was reached.

The toxicity of rotenone to 6 species of fish was studied by Burdick, Dean and Harris (45). Toxicity curves were constructed for comparing the effect of temperature, pH, and variations between species. A wide variation in the exposure required to kill was found in the 6 species. These fall in the order of their resistance as follows: brook trout, rock bass, creek chub, smallmouth bass, common sucker and brown bullhead.

MICROBIOLOGY

Dauer and Sylvester (56) in their 1954 summary of disease reported only four outbreaks for which there was good evidence that water was the vehicle of infection. There were also three other outbreaks in which water was suspected as the source of infection. One of the four water-borne outbreaks was typhoid fever in a coal mining village where water was pumped from a worked out mine into a distributing system of the town. Two outbreaks of gastroenteritis were reported. The three outbreaks suspected of being water-borne were also gastroenteritis and occurred following consumption of water of doubtful sanitary quality.

Archer (17) has described an epidemic of infectious hepatitis in a military camp in Hong Kong thought to be due to contamination of drinking

water with polluted river water. The hazards of a dual system of water supply were emphasized. A water-borne outbreak of amebiasis was studied by Offutt et al. (42, 71, 137) in South Bend, Indiana. Siphonage of raw sewage into the supply line of a private water system was blamed for the outbreak. A leak sufficient to allow sewage contamination was found in the plant water supply suction line between the storage tank and service pumps, at a bell and spigot box on a plant sewer line. Previous difficulties with coliforms in the drinking water had been "corrected" by chlorination (0.3 to 0.4 p.p.m.).

To determine the importance of canal water as a source of infection by Salmonellae in Mendoza, Argentina, 58 water samples were examined by Pallazzolo, Ansiaume, Leiguarda, and Peso (142). Salmonellae were isolated from 82.8 per cent of the samples. Of the 11 species found in water, the six most commonly occurring were also isolated in approximately the same proportions from children exhibiting enteric disorders. Ferramola et al. (72) examined 481 water samples from the Mendoza River (Argentina) and found 31.3 per cent to contain Salmonellae of fifteen species. No relation was observed between the occurrence of Salmonellae and the numbers of coliform bacteria in the samples examined. Six weeks after an epidemic of intestinal disease, Kroger (115) isolated S. bareilly from samples of sewage (Luneburg) and sludge, and on vegetables from the irrigation fields. Steiniger (185) reported that sea birds continued to excrete typhoid and paratyphoid bacteria even after long separation from the polluted water where they were infected. He described the transmission

of typhoid and paratyphoid infections by polluted cistern waters collected from roofs, and discussed the part played by birds in this pollution.

Ljutov (126) of Sweden found that concentration of bacteria by filtration through "Supercel" followed by incubation on solid media was a better method of isolating Salmonellae than previously used methods. As few as five or six pathogenic microorganisms could be detected in 20 liters of tap water. A selenite brilliant green enrichment medium for the isolation of Salmonellae, which has the advantage of being more effective in preventing the growth of Escherichia and Proteus, has been developed by Stokes and Osborne (186).

Pathogenic E. coli, types O-111 and O-55, were recovered by Monnet et al. (133) from drinking water supplies in France. E. coli, type O-111:B4 was found in main water along with other bacterial evidence of pollution following a breakdown in chlorination. E. coli, type O-55:B5 was isolated from shallow well water accompanied by other signs of fecal pollution. Finding pathogenic serotypes of E. coli in main water indicated the necessity of installing adequate treatment to protect consumers from such risks.

Larson, Wicht, and Jellison (118) isolated "a new organism" from a water sample collected in Ogden Bay, Utah. This microorganism designated Pasteurella novicida closely resembles P. tularensis in gross appearance of cultures, microscopic appearance and pathogenicity. It may be distinguished from P. tularensis by fermentation studies and serologic tests. An epizootic of tularemia in beavers and muskrats of

Waterton Lakes National Park, Alberta was studied by Banfield (24). This seemed to be the first time that P. tularensis has been demonstrated in the natural waters of Canada. The height of the epizootic appeared to have been in the autumn, judging by the presence of unutilized feed beds and the first discovery of carcasses. There were no known human cases of tularemia associated with the outbreak.

Two cases of primary tuberculosis following immersion in sewage contaminated water were reported by Miller and Anderson (131). These cases occurred in children aged 4 and 2-1/2 years in northeastern England. The authors reviewed five similar cases from Scandinavia and several papers showing that tubercle bacilli can be recovered from sewage effluents in spite of chlorination.

Rondtorff and Holt (161) have shown that, experimentally at least, cool drinking water is a relatively efficient medium for the transmission of Endamoeba coli and Giardia lamblia cysts. Infections with both species occurred during all periods tested up to 16 days storage. E. coli produced infections in 70.6 per cent of the volunteers and G. lamblia produced infections in 64.7 per cent. These experiments were designed to simulate natural transmission of intestinal protozoan parasites.

Three species of potentially pathogenic fungi have been repeatedly isolated by Cooke and Kabler (53) from polluted water and sewage in southwestern Ohio. Allescheri boydii, Aspergillus fumigatus and Geotrichum candidum appeared to be normal inhabitants of sewage and polluted stream waters. Becker and Shaw (29) studied the fungal flora of

sewage treatment plants receiving domestic sewage at Moscow, Idaho and Pullman, Washington. On the basis of effluents, they concluded that most fungi do not multiply in sewage treatment systems, however, the data presented appear incomplete.

Stokes (187) described morphological and physiological characteristics of the filamentous sheathed bacterium Sphaerotilus natans commonly isolated from stream, pond, and ditch waters. Drumond and Postgate (69) reported a procedure for the estimation of sulphate-reducing bacteria and showed that chromate is a promising specific agent for preventing the nuisance caused by them. Klyunkov, Rogovskaya and Shneerson (112) found that a culture of phenol-destroying bacteria could not be maintained in pure state under conditions of plant use in coke-chemical plants. Because the chemical content of phenolic waste liquors varies considerably, the use of a single bacterial culture did not appear to be practical. Rogovskaya (168) has also discussed the influence of aminocarboxylic acid lactams on microorganisms in water and on the biochemical processes in self-purification of water.

Peso and Mignone (147) investigated the use of bacteriophage as an index of water contamination. They found the bacteriophage technique not superior to the usual bacteriological methods for detection of water pollution. Gilcreas and Kelly (84) examined the relation of coliform organism test to enteric virus pollution. Their experiments indicated that "effective and complete treatment of water was necessary to insure safety from potential pollution by enteric viruses." It seemed safe to

state that the coliform index is still a reliable indicator of significant pollution and of the effectiveness of standard water supply treatment."

Kelly, Clark and Coleman (109) demonstrated the greater effectiveness of gauze pad "swabs" as compared to catch samples for collecting sewage specimens for the isolation of infectious agents. Observations relative to Coxsackie viruses, tubercle bacilli, S. typhosa and S. montevideo isolations were included. The studies indicated that sewage treatment, while complying with existing standards, may not control pathogenic microorganisms to the extent that receiving streams can be ignored as potential sources of infection.

Working at the South District Filtration Plant, Chicago, Vaughn and Scarce (209) supplemented the traditional methods of identifying "lactose-positive" organisms by electron microscope techniques. Twenty-three bacterial strains were isolated from presumptive tubes showing gas. These strains were identified as: Bacillus cereus (16); B. cereus var. mycoides (1); B. subtilis (2); B. circulans (1); Micrococcus candidus (2); and Mic. aurantiacus (1). In a study of additional methods for bacteriological analysis of water, Cope, Dempster, and Chapin (54) found a tetrathionate MacConkey-Kligler system to yield three times as many positive coliform tests as Standard Methods procedures. A second series on well water indicated the use of violet red bile agar gave a higher per cent of positive coliform tests than Standard Methods. Pederson and Skinner (146) compared the productivity of standard lactose broth with lauryl sulphate broth and with the Eijkman methods for demonstrating fecal

coliform bacteria. Under the conditions of the tests, neither lauryl sulphate broth nor Eijkman method was more efficient than lactose broth in eliminating false positive coliform tests when dilutions of feces were used as inocula. Eijkman broth at 45.5 C did not inhibit all strains of Aerobactor in feces. Taylor (192) found that 6 hours incubation in brilliant green bile broth and MacConkey's confirmatory media yielded about 95 per cent of positives obtained after 24 hours incubation. In Norway, Hendrickson (92) compared the efficiency of several methods for detecting coliform bacteria in water. He found that gas production was delayed in MacConkey broth as compared to lactose peptone broth, but that false positives due to Gram positive bacteria were only half as frequent. Frequency of false positive reactions due to Gram negative bacilli failing to produce gas from lactose was very high. Hajna (86) and Damon proposed the use of a buffered desoxycholate glucose broth for primary inoculation followed by buffered desoxycholate lactose broth for confirmation of coliform organisms instead of standard methods media. The data presented indicated a superiority of this procedure over present standard methods. S. B. Thomas et al. (198) reported that the flaming of taps before sampling caused no significant differences in the most probable number of coli-aerogenes organisms or of Bact. coli in water samples. H. A. Thomas, Jr. (194) and Pomeroy (151, 152) discussed statistical treatments of bacterial data. It was believed that the arithmetic mean coliform density as calculated from a series of MPN values from multi-dilution tube tests was a more valid measure of hazard due to enteric pathogens than either the geometric mean or median.

Fischer (75) and Thomas and Hobson (196) pointed out the similarities of intermediate coliform organisms from animal intestines and from the ears and panicles of cereal crops to other coliform organisms usually considered to be indicators of pollution. Thomas et al. (197, 199, 200) studied the bacteriology of farm water supplies in England. The majority of 311 water samples examined contained coliform organisms, a large number of which were E. coli type I. Overnight storage of such water samples, even at 0 to 5 C may cause significant changes in bacterial content, and can result in acceptance of supplies not really safe. Samples should be examined within 6 hours after collection and should be kept at less than 5 C during transportation. Levine, Tanimoto, Minette and Arakaki (121) suggested a boric acid lactose broth medium in conjunction with brilliant green bile broth as a good method for simultaneous confirmation of coliform and E. coli indices from positive or doubtful lactose broth presumptive tubes.

Litsky, Mallmann, and Fifield (125) compared the most probable numbers of E. coli and enterococci at 14 stations on the Connecticut River near Northampton, Mass. The final mean ratio of E. coli to enterococci was 1 to 7.6 as compared with previously reported ratios of 13.3 to 1 and 63 to 1. It was suggested that "the reason for the low numbers of enterococci recovered from sewage and polluted waters by previous methods is not due to their numbers but rather to the failure of the media employed". Dresscher (67) described a liquid thallium sulfate medium for the enumeration of streptococci in water. The test is simple to carry out and takes less time than other means of identifying streptococci

because it is not necessary to make a microscopic examination. Slanetz, Bent, and Bartley (176) developed a new medium for use in conjunction with the membrane filter method for enumerating enterococci in water. In tests with water samples from one reservoir and six rivers, the membrane filter method consistently yielded higher enterococci counts than the Winter-Sandholzer method and the counts in all but three samples were higher than those obtained with the method of Litsky. DeLaney (59) stated that the available data do not warrant the acceptance of the enterococcus group as an adequate indicator of bacterial quality for finished drinking waters. However, he believed that the group would be an excellent indicator of the degree of pollution in such samples as polluted rivers, irrigation water, bathing areas, and shellfish.

In Germany, Karakasevic (107) examined 450 water samples from heavily polluted, moderately polluted and drinking water sources by tube methods using several media, and by the membrane filter procedure (MF). He concluded that membrane filtration is more dependable and more exact for establishing presence of coliform organisms in water. In England, Taylor, Burman and Oliver (191) applied the membrane filter technic to the routine bacteriological examination of water. They obtained higher coliform counts with the MF than with their tube tests. However, the tubes were incubated at 42°C for 18 hours, followed by 6 hours at 37°C. Therefore, the conditions of the tests were hardly comparable. Slanetz and Bartley (175) found that results of tests for coliform densities by the MF technic were in good agreement with results obtained by the Standard

Methods MPN procedures for samples of river and reservoir waters. Of 193 colonies with a sheen isolated from the MF, 97 per cent were confirmed as coliforms, and 58 per cent of these colonies were identified as E. coli by IMViC reactions. Results of investigations by McCarthy (128) indicated that discrepancies between MF and tube technique appeared to increase with time and distance from fresh pollution and that the difficulty of recovering coliforms on the MF increased as the ratio of non-coliform to coliform became greater. He believed that the most urgent need in connection with the MF seemed to be the formulation of a more satisfactory medium. Geldreich et al. (81) developed a delayed incubation MF test for coliform bacteria in water. Estimations of coliform densities in water by the delayed MF technique at 13 to 32° C indicated good agreement with the MPN on stored liquid samples at 5°C. The MF storage results at room temperature and at 35°C were superior to results of MPN procedures on liquid samples stored 24 hours or longer at room temperature or 35° C. Results of statistical analyses by Thomas and Woodward (195) of three extensive investigations on a wide variety of natural waters comparing the MPN and MF techniques indicated that the former gave higher estimations of coliform density by a factor of 1,0 to 1.9 with an average of 1.3 for the specific techniques used. The disparity between MF and MPN values for most of the water samples tested was not significantly larger than discrepancies between results obtained with permissible variations of the standard dilution method. Lieber (122), Bush (46), and Bliss, Steinmetz and Witt (35) have reviewed the development of MF technics and pointed out the advantages and disadvantages attributed to the procedures.

Meleney (130) suggested that the control of schistosomiasis presented problems related to the life cycles of the 3 species infecting man and related also to the various snail vectors, the customs of the human hosts, and the variations in environment. He concluded that each endemic area must be studied individually and that a combination of methods devised by a biological team will be necessary to bring progress in control. Chang (49, 50, 51) has shown that E. histolytica cysts survive in distilled water at 0 C as long as 62 days. He also reported that the destruction of amebae cysts by iodine and silver nitrate is a rate process of the first order and that the poor cysticidal activity of silver nitrate as compared with I_2 is due probably to the poor penetrating power of silver ion into the cysts. Tri-iodide was much inferior to I_2 in cysticidal efficiency. Hannig (90) used bleach liquor successfully in the control of fungi and algae in cooling tower water. After six months of using 8 gm. of Cl per cu. meter, surfaces were clean and the turbine efficiency was markedly improved. Popp (153) has restudied the effect of chlorine for the disinfection of water. Many tests were made using chlorine contents up to 0.6 p.p.m. from various chlorine sources and at different pH levels and bacterial loadings up to 10^8 organisms per ml. His results indicated that the reduction of organisms does not follow exponential law but occurred in two steps. First step was rapid reduction of organisms, lasting about 12 seconds. This was followed by a secondary slow reduction. The killing action of the chlorine was used up during the initial contact period. Polster and

Bochorak (150) investigated the use of solid compounds of hydrogen peroxide in the disinfection of water. One compound produced complete disinfection after 20 to 30 minutes when present in concentration of 0.1 per cent and after 2 hours in a concentration of 0.01 per cent. Chambers et al. (48) showed that many natural waters interfered with the bactericidal action of quaternary ammonium compounds. Bicarbonates, sulfates, and chlorides of calcium and magnesium appeared to be the primary cause of interference. Sodium and potassium bicarbonate did not seriously interfere. Hoather (97), Schmidt, Moller and Thiele (172), and Ricks et al. (166) reported that water can be adequately treated for drinking purposes by ultraviolet radiation provided the water has proper optical density and that sufficient energy reached all the water treated. Technical details relative to wavelength, light source, dosages, and penetrability were discussed.

Berger and Stevenson (30) summarized the feasibility of biological warfare against public water supplies and the nation's ability to prevent or to recognize and ward off a BW attack. Public supplies might be attractive targets and a wide variety of potential agents are available to an enemy, including several not normally associated with drinking water. The distribution system appeared to be a more attractive target than the source of supply. They believed logistics would present no great difficulty. Several recommendations were offered for improved protection of public drinking-water supplies against enemy use of BW agents.

CHEMISTRY

Gloyna (85) presented an excellent review of the effect of laundry wastes on settling, foaming, aerobic and anaerobic processes. The review appears to be aimed primarily at problems presented by laundry wastes from AEC installations.

Hammerton (89) studied the interrelationship of chemical structure of synthetic anionic detergents and their susceptibility to bacterial degradation. Materials containing branched alkyl groups were quite resistant to destruction, whereas straight chain compounds were readily degraded. Major differences in bacterial resistance were not attributable to sulphate and sulphonate groups. Further study of pure materials having various structures was recommended as a basis for further definition of the interrelationships between structure and susceptibility to biochemical attack.

Smith and Subby (178) considered the problem of removal of fertilizing minerals attributable to sewage from lake waters. While organic materials are destroyed mineral enrichment tends to be cumulative. Land irrigation, and holding lagoons followed by filtration were discussed as mineral control procedures for effluents.

Wedgewood (211) has made further investigation of the composition of sewage and trade effluents. He reports that acids are a major portion of the organic material in effluents. In one effluent free of gas liquors, 0.4 p.p.m. of phenol is reported.

The interrelationship of biological populations, dissolved oxygen, and phenol content in the River Pleisse was studied over a nine-months period (10). Certain forms were found highly resistant to phenols. Supplementary laboratory studies of biological resistance to specific phenols are also listed.

Gameson (77) reported studies of self-purification in estuaries. Over-all oxygen transfer was the important factor, with atmospheric oxygen the principal source. In addition to indirect estimation of oxygen transfer by substrate analysis a direct measure of oxygen absorption was attempted by observation of the change in composition and volume of a portion of air held in direct contact with surface area.

OXYGEN SAG AND SELF-PURIFICATION

Both laboratory and field studies to measure rates of atmospheric reaeration of water have been performed by a group of English investigators. Downing and Truesdale (64), in a series of laboratory experiments, studied the effects of mixing, surface wind, waves, temperature and surface contaminants (oil, detergent) on rates of reaeration. In these studies, reaeration rates are expressed in terms of an "exit coefficient", f, defined as

$$f = \frac{V}{A} K$$

Where A is the exposed surface area, V is the volume undergoing reaeration and K is the reaeration constant as usually used in the oxygen sag expression. The exit coefficient is defined as "the rate of change of

oxygen concentration in unit depth of water when the saturation deficit is unity", and the dimensions suggested are cm./hr.

Mixing was accomplished by stirring the water in the laboratory tank. The exit coefficient increased linearly with the rate of stirring up to rates which caused the formation of vortices, after which it increased more rapidly. Surface wind effects were studied by use of a fan whose air stream was directed across the water surface. Both distilled water and sea water were used. In general, wind had little effect until a wind speed of about 10 ft./sec. was exceeded, after which the exit coefficient increased sharply with increasing wind speed. The appearance of the water surface remained unchanged until wind speed reached 10 ft./sec., after which the formation of wavelets and ripples was noted. The authors have indicated here that their laboratory results do not agree with measurements in an estuary. In the latter case, there was a gradual steady increase in rate of reaeration up to wind speeds of about 35 ft./sec.

Heavy fuel oil in thicknesses greater than 10^{-4} cm. materially reduced reaeration, causing the exit coefficient to be reduced by a factor of 4 at an oil thickness of 1 mm. A similar effect, though not so strong, was observed for a light spindle oil. Surface wind of speed 27 ft./sec. greatly enhanced reaeration in the presence of the light oil. Rates of solution were also reduced somewhat in the presence of 1.0 p.p.m. of an alkylbenzenesulfonate, a soluble surface-active agent.

Field studies of the effects on reaeration of anionic synthetic detergents were performed in a small creek by Gameson et al. (79).

Reaeration rates, as exit coefficients, were determined from measurements of dissolved oxygen (Winkler method) at successive downstream locations, after initially deoxygenating the creek water by use of sodium sulfite. This technique is referred to as "direct" reaeration measurement in the sense that the creek was unpolluted by organic wastes and no significant biochemical oxygen demand was encountered. In the absence of detergents it was noted that the exit coefficient, f, varied directly with the stream discharge. The presence of detergent, in concentrations up to 2.0 p.p.m., reduced the rate of reaeration by as much as 40 per cent, but there was no apparent relation between f and the concentration of detergent.

The foregoing paper is of interest in that it considers gasometric methods for measuring reaeration rates, and describes both laboratory and field equipment designed for this purpose. Gasometric methods involve enclosing a portion of air over the water surface and measuring changes in the oxygen content of this air over a period of time. It is pointed out by the authors that any such direct method interferes with movement of the water surface under the enclosing device, leading to false results. Early experiments with gasometric equipment were not as successful as had been hoped, but several means of improving the experiment are suggested.

Measurement of the saturation concentrations of oxygen dissolved in fresh water and sea water in the temperature range 2° - 35° C are reported by Truesdale, et al. (203), and by Gameson and Robertson (78). Dissolved oxygen was determined by the Winkler method, and saturation

was usually approached from below. Care was taken to avoid supersaturation. The measured saturation concentrations for pure water were lower than those given in Standard Methods by as much as 0.4 p.p.m. Saturation values for sea water are also given and compared with other published values.

Self-purification of natural waters has been the subject of several papers (77, 114, 62, 163) and rather general discussions of some of the factors involved in self-purification have also appeared (96, 36). Another simplified version of oxygen sag analysis has been attempted (165).

Buswell (47) indicates that the B.O.D. test does not give adequate information with regard to measuring the "total load" on a stream due to waste discharge. He suggests that adequate measurement of the waste load requires determination of the conventional B.O.D., total carbon, one or more C.O.D.'s, ammonia nitrogen and the concentration of nitrosomonas organisms in the stream. Aside from the large additional laboratory work load involved, this suggested series of determinations does not mention the need for B.O.D.'s measured at times earlier than five days, and for the use of river dilution water and seed if it is desired to know the actual effect of the waste in the stream to which it is discharged.

The effects of several seed materials on the rate of biochemical oxidation have been studied by Gellman and Huekelekian (82). Several industrial wastes as well as four of the alcohols were tested with four

different seeds, including normal sewage, normal activated sludge, acclimatized activated sludge and dispersed growth aeration seed. Acclimatized activated sludge was the most effective seed, while normal sewage was least effective. Oxidation rate constants greater than 1.0 are reported for certain industrial wastes with acclimatized activated sludge seed, as compared to values of 0.1 using normal sewage seed.

Regarding the practical value of acclimatized seeds, these authors state: "The ease with which acclimatization is accomplished suggests that such seed should be more widely used both for waste load measurement and process control (where biological aeration is used as the treatment process)".

That regulation of stream discharge for purposes of power development need not adversely affect a stream is pointed out by Mohler (132), who discusses the results of this practice on the Aare River. In that case no adverse effect has been noted, either in terms of dissolved oxygen or the biological history of the stream. Alter and Porter (2) have reported the results of a one year water pollution survey in Alaska, including evaluation of the asset and liability factors in self-purification.

SURVEYS AND STUDIES

Articles concerning pollution of coastal waters, harbors, streams and ground water have been presented.

Nussbaum, Miller, and Reinhardt (136), summarizing data from several sources, discussed the distribution of pollution within the surf

zone along the California Coast. Water movement within the surf zone is characterized by currents parallel to the shore. They may travel in either direction and may shift from one direction to the other. Pollution discharged into the surf zone will be laterally distributed along the shore, affecting beneficial water uses. Beyer (31) studied the effects of tides, currents, density, and winds on the dispersal of sludge from primary sewage treatment dumped into Oslo Fjord, Norway.

Davis (57) described methods used in the plankton study phases of a pollution survey in the Cleveland Harbor area of Lake Erie and discussed results of the study. He concluded that plankton methods do not provide a reliable index of pollution in localities such as the one investigated and that other available methods (i.e. chemical) are much more sensitive and more easily performed. Filice (74) examined the effect of pH, salinity, oxygen content, and presence or absence of industrial and domestic waste on the invertebrate bottom fauna of the San Francisco Bay area. Sewage is not as detrimental to volume of fauna as industrial wastes, and actually enriches the water outside the zone of greatest toxicity.

Pollution in the Alzette River in Luxembourg was investigated by Krombach, Barthel, and Molitor (116). They report rates of biochemical oxidation for the length of river studied. The tranport of solids in the Meuse River during a severe flood was studied by Beaujean and Leclerc (27). They found that over fifty per cent of the suspended matter carried annually by the river was transported during the course

of this month-long flood. The presence of copper in water used for irrigation from the Watarase River (Japan) was found to have a detrimental effect on the growth of rice in studies carried out by Deguchi (58). An investigation of diffusion of effluent from a submerged industrial waste sewer in the St. Lawrence River near Maitland, Ontario, id described by Reid (159). The objects of the investigation were to confirm that conditions in the River were satisfactory and to obtain general knowledge of the diffusion pattern. Initial work established that an investigation such as this in the St. Lawrence River was extremely difficult. Detailed planning was then made for an elaborate test. Dye was added to the effluent to permit visual observations. A diver was used to establish the trace of the effluent downstream. Direct measurements of waste concentration was made by use of a conductivity meter (the effluent was an electrolyte). Chemical measurements were made on samples taken simultaneously with conductivity readings.

A communication system was provided between the diver, boat crews, and shore crew. Tape recorders were provided to log observations and progress of the survey. Twenty persons, of whom 15 were engineers, composed the survey crew. Results of the diffusion measurements are given.

Halluta (87), in studies on the lower Rhine, found that objectionable taste and odor of bank-filtered water obtained from nearby wells were apparently the result of the passage of phenols and organic acids through the banks.

ABATEMENT AND CONTROL

Legal aspects of abatement and control of pollution continues to be of concern to water users with varied interests. Owen (141) discusses control of stream pollution under the basis of riparian rights by means of court suits for damages or injunctions. In general, the preferred method is by injunction as it provides preventive relief instead of a payment for damages incurred after the fact. Certain limitations to the use of injunctions are listed and the doctrines of balancing of equities and of convenience are discussed with illustrations from court cases. This author concludes that the best solution is a willingness on the part of all to meet in conference and come to some conclusion to the best interests of all concerned from the standpoint of health, public welfare and other conveniences.

Cleary (52) describes in detail some of the policies, practices and problems encountered in the control of pollution in England and Germany. Dornheim (63) describes the powers and duties of the River Boards in England as stated in the Rivers' Board Act of 1948 and the Rivers' (Prevention of Pollution) Act of 1951. The author presents the differences in duties and powers between the English River Boards and the various associations in Germany. The desirability of forming Boards on the English model is discussed. The problems of international rivers are considered. Evans (70) discusses the legal aspects of pollution in the United Kingdom as related to common law, the Rivers' Board Act of 1948, and the Rivers' Act of 1951. Lovett (127) records the history of

the development of pollution abatement measures for England and Scotland. Heaton (91) briefly discusses legislation relating to the control of pollution of surface waters in Great Britain and describes the effects of pollution by sewage, trade waste waters, agricultural wastes, and storm water. Kempf (111) presents information relative to judicial, administrative and legislative aspects of the control of pollution of surface water by trade waste waters in France. Legislation is reviewed of fisheries, and in relation to municipal and industrial water interests. Some recent administrative documents and a list of judicial decisions are appended.

The application of stream standards and classification are discussed by Hess (94) as such may relate to the abatement of pollution. This writer has presented information for allocating the absorptive power or capacity of a stream to assimilate pollution from existing industries and to care for projected industrial expansion. Consideration is given to the assimilating capacity of a stream during critical low flows in relation to factors of safety. Kay (108) stresses the need for a precise policy to be adopted to control the physical, chemical, and bacteriological qualities of surface waters relating to municipal and industrial pollution in Manitoba, Canada. Southgate (181) presents a general discussion of water quality standards including pH, suspended solids, D.O., B.O.D., temperature, organic carbon, C.O.D., color and immiscible liquids. Consideration is given to the suppression of natural purification by pollutants. Fish toxicity tests are discussed in some detail.

The integrated plan of waste treatment as related to other water uses, including potable water supplies, is described by Rohde (169) for the Ruhr District of Germany. In 1952, 270,277 million gallons (U.S.) of water from the Ruhr River was used to supply a population of 4,500,000 in addition to the industries. The high consumption necessitates strict enforcement of regulations concerning reservoir construction. Sewage and waste disposal regulation, which includes diversion of water to the Rhine River, is rigidly enforced. High rate trickling filters are planned for sewage treatment. Treatment to reduce phenols and acids from pickling water liquors is rigidly enforced. The Ruhr Association operates 80 sewage treatment plants, 25 pumping stations, 4 reservoirs, and 48 industrial waste treatment plants, with associated waste collection systems 155 miles long. The reservoirs are equipped with barge locks and are available for recreation. Similar plans for integrated water uses have been developed for the Emscher River.

Financing sewage disposal and water treatment installations on the Thames River, England, are discussed by the Editor of The Surveyor (8). Projects that are approved are supported from funds of the Ministry of Housing and Local Government.

Industries' interest in abating pollution is evidenced in articles relating to the construction of waste treatment facilities. Black (34) outlines varied liquid-waste problems of industry and presents several examples to illustrate present thinking on treatment practice. Types of treatment of wastes are described for the following industries:

petroleum refining, automotive, paper, petrochemical, steel, metal plating, textile, tannery, dairy, food processing, and meat industries.

Pettet and Ware (148) discuss treatment of cyanide wastes by biological systems. They state that up to 1 to 2 p.p.m. of cyanide can be tolerated by biological treatment systems. It is recommended that direct stream disposal should be avoided.

Horner et al. (101) discuss the use of electrolysis in relation to waste pickle liquor. Such liquor is subjected to electrolysis across an anion-exchange membrane. Sulfuric acid is collected on one side of the membrane and electrolytic ion is deposited at the cathode on the other side. The costs are comparable to lime neutralization.

A number of articles dealing with the treatment of textile wastes have been published. A bibliography on textile mill wastes was compiled by the Stream Sanitation Committee of the Piedmont Section of the textile industry (5). This includes information relative to textile waste properties, waste reduction and prevention, waste treatment, legal requirements, economics of treatment and disposal, and general information on industrial waste control. An industrial waste guide to the wool processing industry (4) that should be of general interest to those working in water pollution control, has been published. Steele (184) outlines the progress the textile industry has made in recovering caustic. The experience of several bleacheries is given as an example of the practicality of recovering caustic, thus alleviating pollution. Stafford and Northup (182) present data of the 5 day B.O.D. for about 154 textile

chemicals, as an aid to textile mills interested in careful and controlled disposal of chemical wastes to minimize stream pollution. Brown (43) presents data from a two year study of bleaching and dyehouse wastes. Souther and Alspaugh (180) report on pilot plant studies, using mixtures of domestic sewage and textile mill dye and finishing wastes by high rate trickling filters, by activated sludge, and by chemical treatment to determine the most efficient and economical method for treating such wastes. Contradictory to published reports stating that sewage and industrial wastes with high alkalinity cannot be successfully treated in an activated sludge plant, results from the authors' research indicate that pretreatment by trickling filters and subsequent treatment through activated sludge is a most efficient method. An unusually high B.O.D. and color removal is obtained. Snyder (179) discusses the problem of stream pollution resulting from discharge of process wastes from Crompton-Shenandoah's dyeing and finishing plants. Consideration is given to the steps taken toward solving the problem by substituting synthetic, film-forming, compounds for natural sizing materials. The possibility of reducing over-all pollution from cotton dyeing and finishing plants, by as much as seventy per cent, is indicated, through the use of chemical substitutions. Smallhorst (177) presents a brief and condensed report on the activities of the Texas State Department of Health in determining methods of treating textile mill wastes to render them suitable for discharge into a municipal sewerage system.

Pulp and paper mill wastes are reported as having been reduced by activated sludge treatment at Jackson River, Virginia (6). By the

addition of nitrogen and phosphorous to activated sludge, organisms develop which are effective in reducing the effluent B.O.D. from 140 to 15 p.p.m. With such treatment, now removing oxygen demanding wastes from the stream, fish have moved 20 miles upstream from their former limited range. Webster (210) presents information relative to the use of natural ponds and creeks as waste treatment facilities by the National Container Corporation's New Valdosta Mill in Georgia. Wetherhorn (213) gives a report on reductions in effluent B.O.D., brought about by changes in the recovery system of the Southern Paperboard Corporation's plant at Port Wentworth, Georgia. Surveys were carried out prior to and during the incorporation of changes in the waste disposal system. Survey data are presented.

The creation of new pollution is pointed out by Lang (117) who discusses air pollution corrective measures as they may complicate water pollution control problems. Of a number of papers that he reviewed only five per cent on wet methods of air pollution control made reference to the effect of the method on water pollution. He states that scrubbing, and absorption methods of air pollution control results in sludges, wash water, filter cake and froth, which if discharged to streams are likely to produce water pollution problems. Disposal of relatively dry concentrates by burial with recycling of liquid treating agents should be preferred over disposal of such wastes in a stream. Both the engineer and control officials should carefully consider the interrelationships between water and air pollution control.

STREAM STANDARDS

Weir (212), Rhame (164), and Hubbard (102) discussed the classification of streams in Georgia, S. Carolina, and N. Carolina respectively and Young (221) outlines the cooperative program of the U. S. Public Health Service in pollution abatement. Georgia does not classify streams in the usual sense whereas formal classification of streams is a part of the pollution control procedure in both of the Carolinas.

Bacon and Sweet (18) and Rawn and Bacon (158) described the four step process by which water quality criteria are set and waste discharges are controlled in California, and discussed the relationship of these water quality criteria to the overall California Water Plan.

Powell (156) has described the varying principles employed in different states in classifying streams.

Mueller (134) concluded that in order to avoid excessive growth of algae and aquatic weeds nitrate N should be kept below 0.3 mg. per l. and total N below 0.6 mg. per l.

The Bi-State Development Agency in its report on pollution of the Mississippi River in the St. Louis area (33) recommended a combination of effluent standards and stream standards. The report recommended that phenol concentrations in the stream be limited to a monthly average of 2 p.p.b. and a maximum of 5 p.p.b. and that the threshold odor number be limited to a monthly average of 10 and a maximum of 30.

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